



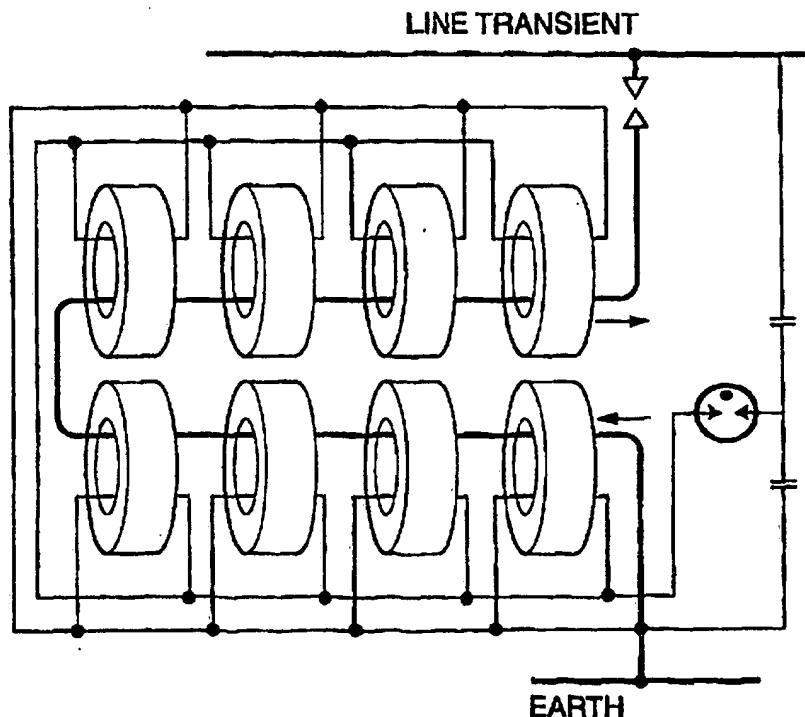
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(54) Title: OVERVOLTAGE PROTECTION SPARK GAPS AND TRANSFORMERS

(57) Abstract

The present invention relates to the technology of igniting spark gaps, particularly lightning arresters. The present invention also relates to lightning protection and transient protection. The present invention has many applications, such as electrical transmission lines, electrical supplies and sources, and telecommunications. One aspect of the present invention is directed to using a matrix transformer for the triggering of spark gaps. In a further aspect of the present invention the secondary conductor of the matrix transformer is folded back on itself so that, in the saturated mode, the magnetic linkage between the forward and the reverse section will act to further reduce the inductance. In a still further aspect of the present invention, there is provided a spark gap electrode, comprising at least two frusto conical sections mutually opposed, and being spaced by an insulative material, the sections having a hollow therethrough, into which a conductor can be placed.



## OVERVOLTAGE PROTECTION SPARK GAPS AND TRANSFORMERS

## FIELD

The present invention relates to the technology of igniting spark gaps, particularly lightning arresters. The present invention also relates to lightning  
5 protection and transient protection.

The present invention has many applications, such as electrical transmission lines, electrical supplies and sources, and telecommunications.

## BACKGROUND

Known transient protectors for controlling switching and lightning induced  
10 transients comprise spark gaps which are commonly called voltage switching devices and metal oxide varistors (mov) which are known for their voltage clamping function. There are also solid state devices which fall into those categories but these are mostly incapable of economically handling high energy transients. Each of these devices have technical advantages and  
15 disadvantages. The spark gap can handle very high currents as the initial switch-on voltage of the arc is a low 50V. However, when these devices are placed across a power line, the low arc voltage will cause a follow current to flow after the transient has passed. Thus, in simple terms, there is a problem associated with turning off the arc, once the transient has passed. These  
20 currents can only be restricted at the next power zero crossing. A further disadvantage of the spark gap is that they require a relatively high spark over voltage. Values are typically 3.5kV which is a high level for protecting a 240Vac circuit.

The spark gap may have a mov placed in series which will act to add  
25 voltage to that of the arc. The combined voltage then becomes sufficient to limit the power follow current. The disadvantage of this arrangement is that the mov becomes the limiting device as far as power handling capability is concerned.

Conversely, movs may be used without a spark gap. When rated for  
275V on a 240Vac circuit, they will have no follow current and can enter  
30 conduction at around 450V with voltage rising as the transient current increases.

Devices designed to protect 240Vac circuits would typically rise to values of 1500V as they near their energy absorption limit. Further, the mov suffers degradation with each high energy pulse and so has a finite lifetime.

It is one practice to place spark gaps at the building entrance and movs  
5 downstream and near the protected equipment. This can only work if there is decoupling between the two devices as the mov can prevent the spark gap reaching the trigger voltage. If the trigger voltage is not reached, all the energy is transmitted to the protected device and both the mov and the equipment can be destroyed. In this situation, the mov has inadequate energy rating. In order  
10 to overcome this effect in a practical solution, a series inductance must be placed in the line as a decoupling element. This practice is known in the industry as "co-ordination of protective devices".

International Patent Application PCT/AU95/00768, filed by the present applicant, disclosed inserting a pulse transformer in series with the gap in order  
15 to facilitate firing of the sparkgap. This transformer could create, at an appropriate moment, an additive voltage to that across the electrodes of the gap. The advantage was that a gap could be induced to strike at a far lower voltage than normal voltage.

It has subsequently found that this arrangement places an inductance in  
20 series with the spark gap. A transient pulse being diverted by the gap would have a high  $di/dt$  which, when combined with inductance of the transformer winding, would create an additive voltage capable of exceeding the original spark over voltage. This arrangement acts to reduce inductance with saturated core values in the order of 500 nanoHenries being achieved.

## 25 SUMMARY OF INVENTION

In order to understand the present invention, it is necessary to start with the spark gap trigger mechanism. The concept of this spark gap trigger mechanism is disclosed in copending PCT application No. PCT/AU95/00768, as noted above. The aim of this mechanism is to produce an additive voltage in  
30 series with the gap when a transient exceeds a preset value. This is performed by a step up transformer. The present invention can be considered an improvement to the invention disclosed in PCT/AU95/00768.

Normally, such an additive voltage technique would not be considered by those skilled in the art, since the transformer winding in series with the gap would be subject to the entire transient current flow once conduction commences. The inductance of this winding plus the high  $di/dt$  of typical transients would mean that  
 5 some thousands of volts would be added to the arc voltage. This would totally negate any perceived advantage in causing the gap to trigger at a low voltage.

One aspect of the present invention is directed to a transformer of special construction adapted to produce an additive voltage. This aspect of the present invention is based on using a matrix transformer for the triggering of spark gaps.  
 10 Matrix transformers have theretofore been used in power supply design, but in such designs, the matrix transformer is not used in a saturated mode.

This aspect stems from the realisation that problems associated with the prior art, such as the relatively high inductance values achieved in operation of the prior art arrangements, can be reduced by the use of a matrix transformer and  
 15 which transformer operates in a saturated mode, in an ignition device for a sparkgap.

In a further aspect of the present invention, it has been realised that the inductance can be further reduced by utilisation of at least partial cancellation of magnetic fields. This aspect may be provided in the form that the secondary  
 20 conductor of the matrix transformer is folded back on itself so that, in the saturated mode, the magnetic linkage between the forward and reverse section will act to further reduce the inductance.

#### PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will now be described with  
 25 reference to the accompanying drawings, in which:

Figure 1 illustrates a 4:1 step up transformer,

Figure 2a illustrates a 6:1 step up transformer,

Figure 2b illustrates the proximity of the return wire to the core section,

Figure 3a illustrates a basic triggering device,

30 Figure 3b illustrates a 8:1 step up transformer sidactor triggering with straight wire in series with the spark gap,



Figure 4 illustrates a step up transformer in loop back system to further reduce inductance,

Figure 5 illustrates a 8:1 step up transformer in loop back system using E-I cores,

Figure 6 illustrates a gas arrested triggering with two series connected spark gaps

5 used to reduce follow current,

Figure 7 illustrates a resistor biasing of capacitive divider,

Figure 8 illustrates an alternative capacitive element arrangement,

Figure 9 illustrates an isolation between the primary and secondary trigger transformer,

10 Figure 10 illustrates a 12:1 transformer with two "U" sections,

Figure 11 illustrates a new electrode,

Figure 12a, 12b and 12c illustrate magnetic fields and arc movement around the electrode,

Figure 13a and 13b illustrate a second magnetic effect,

15 Figure 14a and 14b illustrate an alternative electrode construction, and

Figure 15 illustrates an example application of the aspects disclosed.

Normal transformer windings, even when the core is magnetically

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saturated, are wound one upon another and so reinforce each other in a manner to produce a high residual inductance. Values of the order of 4 microhenries are typical. One improvement over conventional winding, is to use a toroidal core. When this core saturates, the windings do not directly  
5 complement each other in order to increase inductance. Each turn produces a north and south pole along a line which is at right angles to the winding direction. Since the windings continually change direction around the 360 degrees of the toroidal core, the additive effects due to normal winding are reduced. Typical values would be 0.5 microhenries.

10 The matrix transformer of this invention has the advantage of zero complete turns. The winding is actually a straight piece of wire as shown in Figure 1. When the secondary is folded back as in Figure 4, typical values of inductance under core saturation reduce to 0.15 microhenries.

Of course, the secondary may be made up of more than one turn to  
15 achieve larger output voltage as shown in Figures 2a and 2b, but there will also be an increase in the saturated core inductance.

In summary, normal transformers achieve a voltage increase by using a single core and a suitable turns ratio. In this invention, however, the principle noted above is applied by using a number of individual transformers of  
20 preferably 1:1 ratio which are parallel connected in the primary and series connected in the secondary. The step up ratio is determined by the number of transformers. Preferably, the cores of the transformers are ferrite.

In this invention, the disadvantages of the spark gap are alleviated and triggering voltage becomes controlled at a relatively low value, typically in the  
25 range of 500-600V for a 240Vac circuit. The follow current becomes controlled and a long lifetime is assured. The need to decouple downstream devices is substantially eliminated, as the residual voltage from the invention leaves only a few amperes to flow in the direction of the equipment. A further advantage is that the low residual currents have insufficient energy to induce significant  
30 voltages into adjacent cables.

Figure 1 shows a preferred arrangement of the present invention. Conventional practice is to wind a transformer on a single core and to increase

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voltage by setting an appropriate turns ratio. In this invention, multiple cores are used with their primaries being parallel connected to the trigger source. Figure 1 shows how a 4:1 step up transformer can be achieved using this technology.

- 5 Each primary winding can be a single turn, while the secondary is a straight piece of wire passing through each core. As the secondary wire passes through each core, a voltage is added in the same manner that would occur with an in

phase series connection of windings in a conventional transformer. Notably the secondary winding may be a straight piece of wire which, over a distance of approximately 100mm, can have an induced voltage exceeding 4kV. The parameters of the core material are then selected to allow them to saturate at very low flow currents in the secondary, typically 1-2 amps. The ability of a straight piece of wire in the secondary of a multiple core transformer matrix to be able to develop very high voltages, and then, to have the cores saturate with low levels of subsequent current flow is not immediately obvious. The benefit is a reduction in inductance to values as low as 50-150 nanoHenries, depending on the number of cores required, the number of turns for the specific application, and the consequential length of wire used. If the secondary winding is then made to fold back as shown in Figure 5, and additionally is constructed of two sets of "E" cores, then that winding becomes like a non inductive resistor when the core is saturated. The use of the "E" cores with a primary winding around each leg means that two cores produce a 4:1 step up ratio. It can also be useful where space is limited, to reduce the number of cores and to pass the secondary winding more than once through the cores. This concept is shown in Figure 2a. The disadvantage is that there will be an increase in the inductance of the secondary when in the saturated core situation. However, because of the proximity of the return wire to the core section as shown in Figure 2b, it will be observed that the magnetic effects of two sections under core saturated conditions will try to cancel. This feature in the construction geometry of the transformers, reduces the expected increase in inductance which would normally be according to the square of the turns ratio.

25        A simple trigger mechanism for the transformer is shown in Figure 3a. Figure 3b shows an example of a triggering device in which a pulse is created at a transient level of approximately 500V. Using eight toroidal cores and a 1:1 ratio, the straight wire secondary builds up to approximately 4000V, while the winding inductance in the saturated mode will reduce to approximately 200 nanoHenries. Other arrangements where the present invention is equally applicable are shown in PCT/AU95/00768. The gas arrester fires at a voltage determined by the transient level and the capacitance ratio of the two capacitors.

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The energy of the capacitor is then dumped into all primary windings with their parallel connection arrangement.

The transformer secondary can be made of heavy cable or flat strip in order to carry the full impulse of the spark gap. This could be a 100kA x 8/20 5 usec impulse. In a practical situation, some 4kV can be added to the line transient of say 500V to make an impressed voltage on the gap of 4.5kV. This incremental voltage can be achieved in the order of 50 nanoseconds. Conversely, the winding inductance of the secondary can be reduced to as little as 150 nanohenries in the saturated core mode.

10 The overall effect is that a 20kA impulse with a 10 microsecond rise time with  $dI/dt$  of 2kA/usec can be impressed across 0.15 microhenries. This will produce a voltage according to  $L \cdot dI/dt$  of 300V, which is then added to the initial spark voltage of 50V. The entire invention becomes capable of triggering at say 500V and limiting a 20kA impulse to 350V.

15 A second aspect of the present invention will now be described. In Figure 4 the secondary conductor is folded back on itself so that, in the saturated mode, the magnetic linkage between the forward and reverse section will act to further reduce the inductance to a value of approximately 100 nanoHenries. In this variation, the cores are placed on both sides of the secondary "U" section. The 20 reduction in inductance is achieved with essentially the same secondary conductor length as in the straight wire version. This principle is further extended in Figure 10 where additional "U" sections are added in a three dimensional arrangement. In this innovation, the current in any one arm of a "U" section will be in opposite direction to all neighbouring sections. In a practical 25 arrangement of this invention, a double "U" will have an inductance of approx 120 nanoHenries compared with a value of 600 nanoHenries for a straight wire of similar length.

By combining two adjacent toroids, E-E or E-I shaped magnetic material can be used. The circuit of Figure 4 can be reproduced with just four E cores as 30 shown in Figure 5. In this arrangement, each E core now provides a 2:1 step up voltage.

Figure 6 is another variation where two spark gaps are used in series so

that, after they have struck, their arc voltages will add. This is desirable since the combined arc voltage will be higher and consequently the power follow current will be lower. In this case the voltage increment supplied by this invention is placed in series with the centre junction of the two spark gaps.

- 5 Because of the series nature of the key components, the invention will work equally well if the trigger transformer secondary winding is placed between line and spark gaps, or between spark gaps and ground.

The capacitive divider of Figure 6 sets the firing voltage of the gas arrester. The two capacitors in series also serve to provide the necessary pulse  
10 current required in the primary of the trigger transformer to magnetise the core. Optional biasing resistors may be added across each or both of these capacitors as shown in Figure 7. The resistor function to bias the capacitor voltage, and also bleed any voltage across these capacitors when the voltage is disconnected. This biasing may or may not have frequency dependence. If the  
15 ratio of  $R1/R2 - C2/C1$  is used, the biasing resistors and capacitors will create a frequency independent division of the mains voltage. Typically, the values of these resistors would be greater than 100 kilohms to limit resistor power dissipation when operating at mains voltage.

A further arrangement of the capacitive elements involves the trigger  
20 transformer arrangement of Figure 8. In this case, the capacitor C1 provides the energy for the trigger to switch through the transformer primaries. This circuit may have some or all of the optional resistors across the capacitors for biasing. In this variation, the resistor R2 may be added. This acts to make the trigger circuit frequency dependent. At low sinusoidal mains type frequencies, values  
25 for the resistors and capacitors are chosen such that the voltage between point "P" and "Q" is too low to trigger the gas arrester. As this frequency is increased, the impedance of capacitor C2 reduces, however the resistor impedance does not. The net effect is that the voltage of point "P" increases. The intention of this frequency dependent trigger is to have a lower gas arrester firing voltage to fast  
30 transients than to slow mains frequency voltage waveforms.

If this device in combination with a spark gap is protecting between a line voltage and earth, then there will be an issue of earth leakage current to

consider. Typically the capacitive divider will only draw milliamps of current from the mains if there is no triggering. An alternative arrangement can be used to prevent the capacitive current flowing into the earth line if the secondary of the trigger transformer is isolated from the primary. A typical application for this is  
5 given in Figure 10. The capacitive divider, is driven between the line to neutral. If a transient exists between line to neutral, the trigger circuit will operate the spark gap and the surge current will be passed from active line to earth.

The improvement over the prior art is beneficial because it produces a faster triggering pulse, from a smaller package with significantly lower saturated  
10 inductance.

When spark gaps are designed for only random operation such as would occur with lightning events, their operation frequency may be several times per year. With this invention, operation is caused at a lower incident voltage such as would occur with switching impulse generated within a building. These may  
15 occur several times per day and increase the operating duty several hundred times that for lightning. Spark gap life time then becomes an important criteria as electrode burning may significantly alter performance criteria.

In the past, manufacturers of spark gaps had the dilemma of wishing to reduce the initial spark gap in order to lower the spark over voltage. However,  
20 below a certain limit, metal fingers could form from the arc process and short out the gap. Thus, for typical gaps, around 1mm became a minimum value, and even using surface discharge techniques, spark over below 3.5kV is rarely achieved. The use of the trigger transformer of this invention allows a controlled high voltage to be placed in series with the gap while the impressed transient is  
25 at a low voltage. This allows the primary design parameters of current spark gaps to be improved. For example, the current initial spark gap may be increased from 1mm to 2mm, and result in the doubling of the initial arc voltage. This will minimise the initial magnitude of the power follow current.

Further improvements can now be made to the spark gap in order to  
30 control electrode burning and to force the arc to expand and so increase the arc voltage. This voltage increase will ensure that the arc will extinguish well in advance of the next current zero.

Because of the advent of incremental voltage triggering, improvements to conventional spark gap technology can now be made. There is no longer a need to maintain a very small initial gap in order to keep the spark over voltage as low as possible. The initial gap can be extended in length by designing the trigger transformer to have a high output voltage.

There still exists a problem of extinguishing the arc once the gap has been fired. To this end, the improved spark gap arrangement of this invention due to incremental voltage triggering may use two magnetic effects to expand the arc and to limit electrode burning. Figure 11 shows how two truncated conical elements are separated by an insulating medium. A permanent magnet is shown at 1 and 4, insulation is shown at 2 and conductive cones are shown at 3. The insulation is designed to make the initial arc track along the insulator surface.

Figure 12a shows the magnetic field when two gaps are connected in series. Each insulation is made in the form of a curve as shown in Figure 12b. This will make the arc move out horizontally on the upper surface, then down and return on the lower surface. Numeral 8 illustrates current flow around the insulator. Since both horizontal sections are in the same magnetic field, the upper section will move in one direction 6 and the lower section will move the opposite direction 7 according to Figure 12c. Numeral 5 indicates that the arc is vertical at initiation.

The second magnetic effect is shown in Figure 13a. It is achieved by passing the conductor for the lower electrode vertically down through the center of the cones. Numeral 9 shows the conductor in cone electrode. Numeral 10 shows return current in arc. The magnetic effect of the downward conductor current flowing to the lower electrode will then act upon the magnetic effect of the upward return current in the arc. Thus, the arc will be slewed by the permanent magnet and radially expanded at a rate dependent on the magnitude of the arc current as illustrated in figure 13b. Numeral 11 shows arc movement. This is an electromagnetic effect.

Figure 14a, an improved electrode is shown which is particularly suited to the advantages of the incremental voltage triggering made possible by this

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invention. Permanent magnets are shown at 12, insulators at 13 and conductive cones at 14. The arcs within multiple gaps may be both rotated and forced to extend their arc length to reduce follow current and to assist the extinction process as illustrated in 14b. Numeral 15 illustrates the magnetic force.

- 5 Referring again to figure 14a, the current path again is made to form a "U" by passing an insulated wire conductor down through the center of the truncated conical sections forming the electrodes. When the arc is triggered by the transformer, it is in the reverse arm of the "U". In

this location it is a current flowing in air and is not confined within a mechanically rigid conductor. The interacting electro magnetic forces cause the vertical arc to expand outward along the surface of the cone electrodes. Circular magnets in the form of an "annulus" may be located on the bases of the  
5 cone electrodes with like poles facing. This creates a radial outward radiating magnetic field which, in the presence of a vertical arc, will cause the arc to motor (rotate) horizontally around the electrodes.

The technology of this spark gap has not been realised in any prior art, since the design criteria was always to minimise the length of the initial gap and  
10 to achieve the lowest spark over voltage. The innovative aspects of the trigger transformer leads to a consequential improvement in spark gap technology.

The technology of this invention may use a single gap for the lower line voltages such as 115Vac. When it is necessary to control higher line voltages, a further improvement may be obtained by placing two such gaps of this concept  
15 in series. Once the combined voltage of the gaps exceeds the instantaneous value of the power supply voltage, the arc will extinguish. Conduction of any follow currents may be restricted to values of 1 millisecond or less, and will be incapable of tripping a circuit breaker.

The invention enables use of an insulating piece with a physical  
20 magnitude determined by the available trigger transformer voltage, and a double magnetic effect by combining permanent and electromagnetic fields to both slew the initial arc and to extend it radially. Thus, the arc voltage is increased to reduce follow current and the arc extinguishes earlier. It cannot be maintained if the arc voltage exceeds that of the power supply.

25 In order to complete this invention it is necessary to consider the very short period in which a transient voltage may occur between the establishment of the arc, and the saturating of the transformer cores. The limiting of this transient is achieved by placing a voltage clamp across the line or, by the inclusion of a low pass filter. A combination of both will lead to extremely low  
30 residual voltage from very high transient impulse currents.

Figure 14 shows a schematic of the invention in use. Where the circuit is used with equipment designed to operate at 240V, the diodes may be designed

to have a threshold of conduction near 450V and to reach their energy limit near 650V. For other line voltages, obviously other diodes and thresholds can be suitably chosen. This has the advantage that the diodes will clamp all small transients and the trigger gap will assume the load when the voltage exceeds  
5 say 550V.

The final advantage lies with the parameters of downstream filters. Normally filters are tested with a waveform of 8/20 microsecond. However, these are not representative of the surges found in nature where tail lengths of some 100's of microseconds exist. The residual transient of this invention exists  
10 only in the period before transformer core saturation, a time of approximately 100 nanoseconds. This time period is relatively constant and essentially independent the waveform of the impressed transient. Because of this very short time and the prior clamping, the inclusion of a simple L/C filter will further reduce the residual voltage and will complete the overall design.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An improved spark gap triggering mechanism, the improvement including a matrix transformer forming a part of the trigger mechanism, and which when in use, the matrix transformer operates in a saturable mode.
2. A mechanism as claimed in claim 1, in which the mechanism is coupled in series with the sparkgap.
3. A mechanism as claimed in claim 1, wherein the transformer has primary winding coupled in parallel and secondary winding in series.
4. A powerline transient overvoltage protector comprising the mechanism of claim 1, in combination with a single or plurality of series connected two element spark gaps, the spark gap(s) being triggered into conduction by the mechanism, and having the mechanism placed in series with the spark gap(s) to produce an pulse voltage, in addition to the line voltage, sufficient to trigger the spark gap when line transient exceeds a predetermined threshold.
5. A protector as claimed in claim 4, wherein the spark gaps have follow current quenching properties, utilise a surface discharge across an insulating medium at the moment of conduction, and have both a fixed magnetic field and a current dependent magnetic field to expand and rotate the established arc;
6. A protector as claimed in claim 4, coupled in shunt across the line to be protected.
7. A mechanism as claimed in claim 3, wherein the secondary windings are constructed of fold back conductive strips.





8. A mechanism as claimed in claim 3, wherein the secondary winding comprises a straight wire or metal strip formed to carry the full rated current of the sparkgap(s).
9. A mechanism as claimed in claim 8 wherein the transformer has at least one core with at least two winding windows allowing for the provision of at least two primary windings and a conductor forming the secondary winding.
10. A mechanism as claimed in claim 9, when appended to claim 8, wherein the wire or strip is configured to pass through a number of the cores in order to sum the voltage generated in a number of stages.
11. A mechanism as claimed in claim 10, wherein the core is formed from "E" and/or "I" shaped elements.
12. A mechanism as claimed in claim 11, wherein the core is formed of a material which will saturate upon flow of current over the sparkgap.
13. A mechanism as claimed in claim 9, wherein the secondary windings exhibit magnetically neutral characteristics when the core material becomes saturated with the flow of current through the spark gaps, thereby producing a very low residual series inductance in the spark gap assembly.
14. A mechanism as claimed in claim 3, wherein the secondary windings are constructed of at least 2 sets of "E" cores.
15. A mechanism as claimed in claim 14, wherein the winding exhibits characteristics similar to a non inductive resistor when the core is saturated.
16. In combination,  
a protector as claimed in claim 4 and



a voltage limiting device which is connected across the assembly to limit the very brief period of overvoltage due to high  $di/dt$  and the transformer inductance in the period from conduction of the gap to the advent of core saturation.

17. In combination,

a protector as claimed in claim 4, and

a low pass filter connected across the assembly.

18. A protector as claimed in claim 4, wherein the magnitude of the voltage on the AC line determines the number of series connected spark gaps.

19. A matrix transformer used in conjunction with a sparkgap trigger mechanism, the transformer having a primary and a secondary winding, wherein the secondary winding is at least partially configured to form a "U" shape such that in operation in a saturated mode partially opposing magnetic fields are formed which serve to reduce the residual inductance.

20. A mechanism as claimed in claim 3 or 9, in which at least one of the windings are formed from tracks on a printed circuit board.

21. A mechanism as claimed in claim 20, wherein the tracks are coated with an insulative material

22. A mechanism as claimed in claim 3, in which an avalanche switch such as a gas arrester or solid state switch is used to dump capacitor energy into the primary windings.

23. A mechanism as claimed in claim 22, wherein a voltage trigger level is derived from a capacitive divider arrangement coupled in parallel with the mechanism, the center tap of which divider arrangement, feeds to the switch leading to transformer primaries.



24. A mechanism as claimed in claim 23, wherein resistors are placed across the capacitors in the ratio  $R1/R2 = C2/C1$  to produce a frequency independent division of the impressed voltage.

25. A mechanism as claimed in claim 24, and in which a capacitor C1 becomes the main energy source to feed the transformer primary winding, and connected in parallel across the sparkgap and transformer, series coupled resistors R1 and R2 providing a controlled frequency dependence whereby the resistors, at mains frequency, form a voltage divider with a junction voltage below the avalanche switch trigger operating voltage, which in operation, the application of a fast rising waveform will serve to lower the impedance of C2, increasing current flow and voltage across R2 to a level sufficient to operate the trigger.

26. A mechanism as herein disclosed.

**DATED** this 17th day of July 2000

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Fig1.

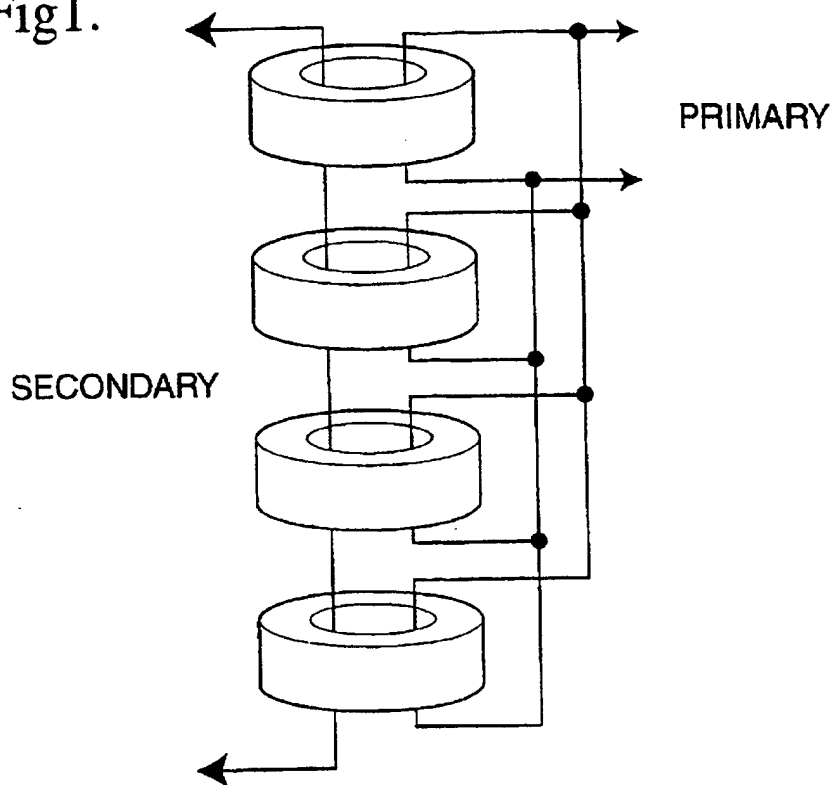


Fig 2a.

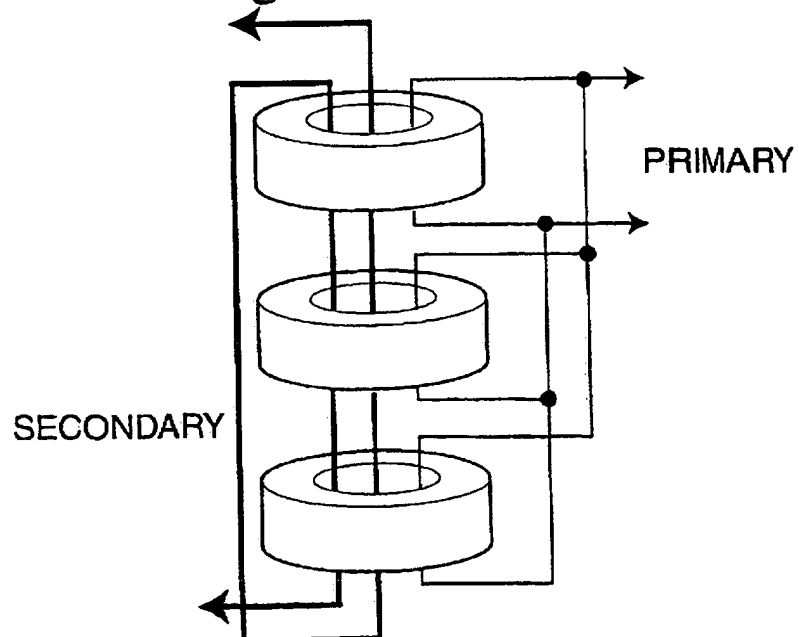
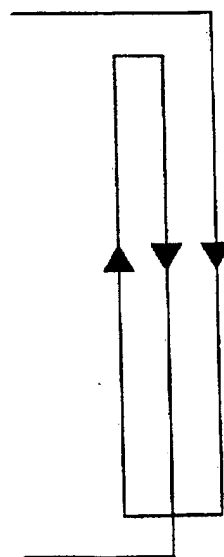


Fig 2b.



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Fig 3a.

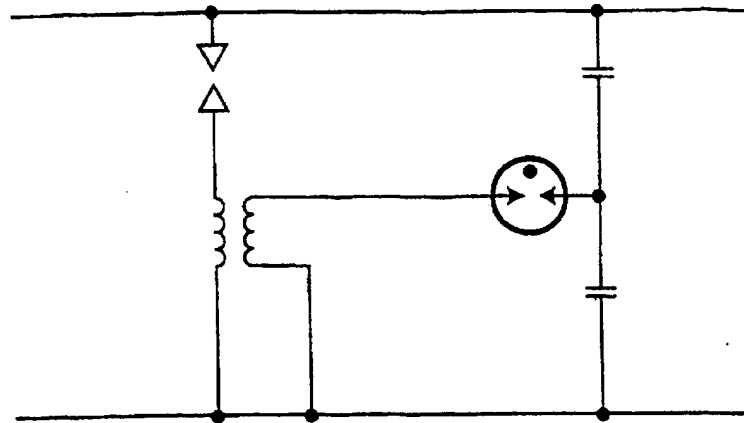
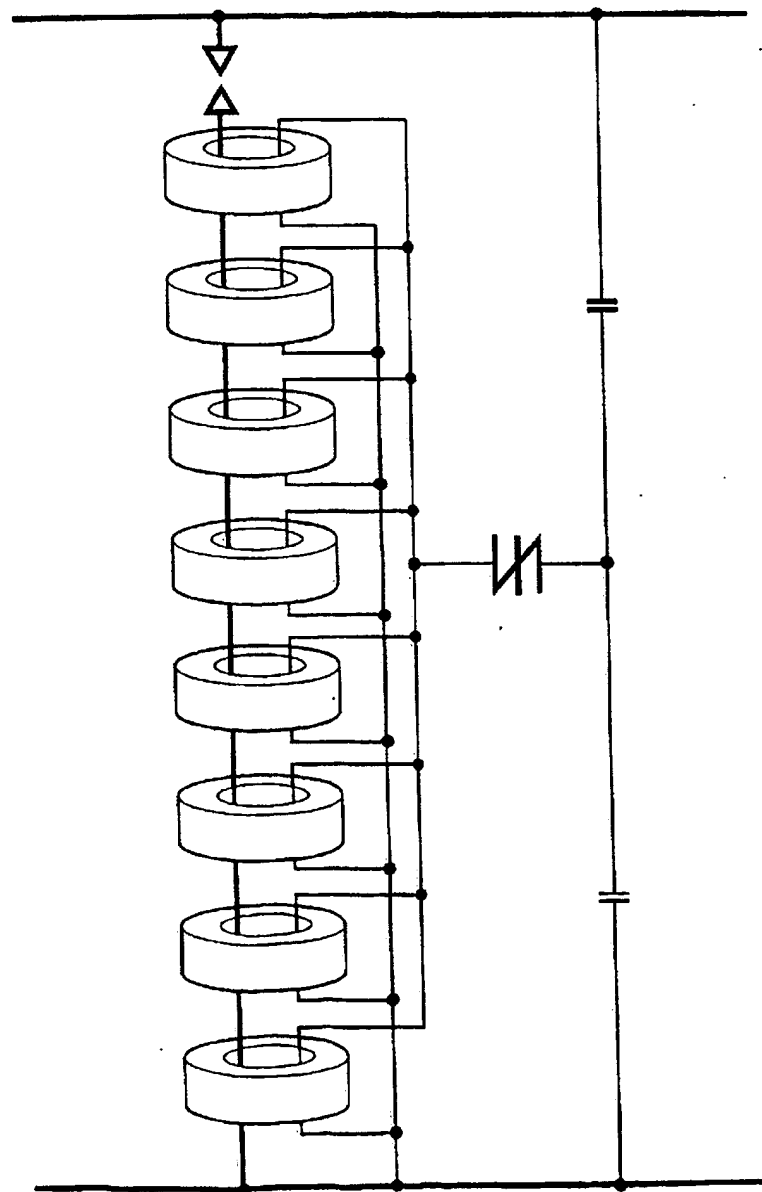


Fig 3b.



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Fig 4.

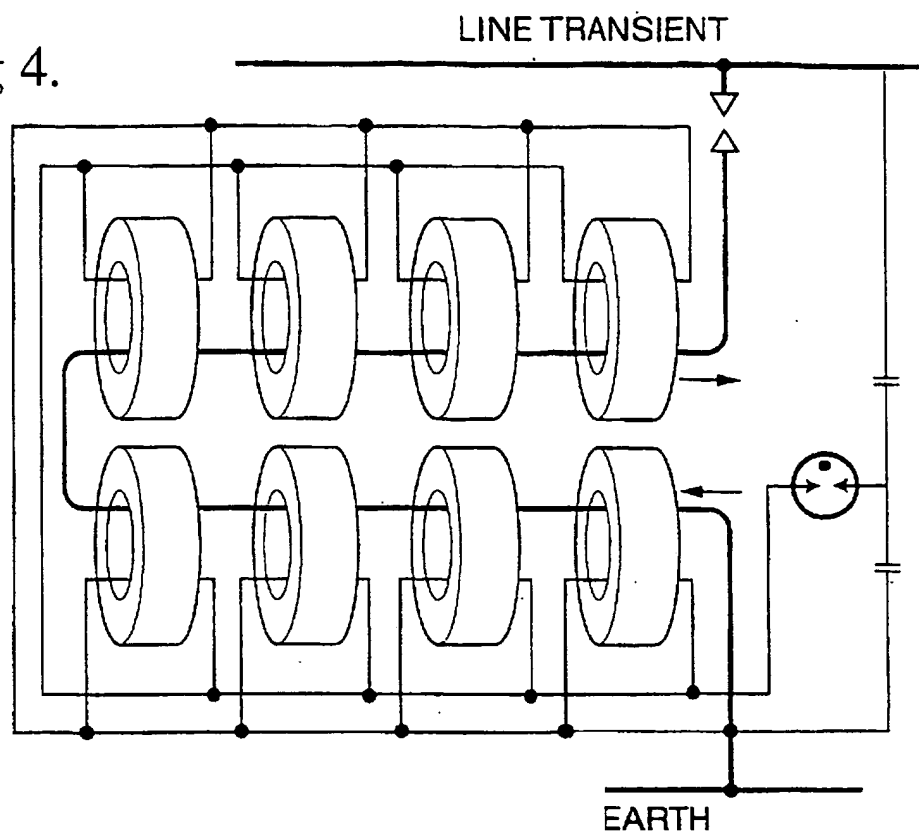
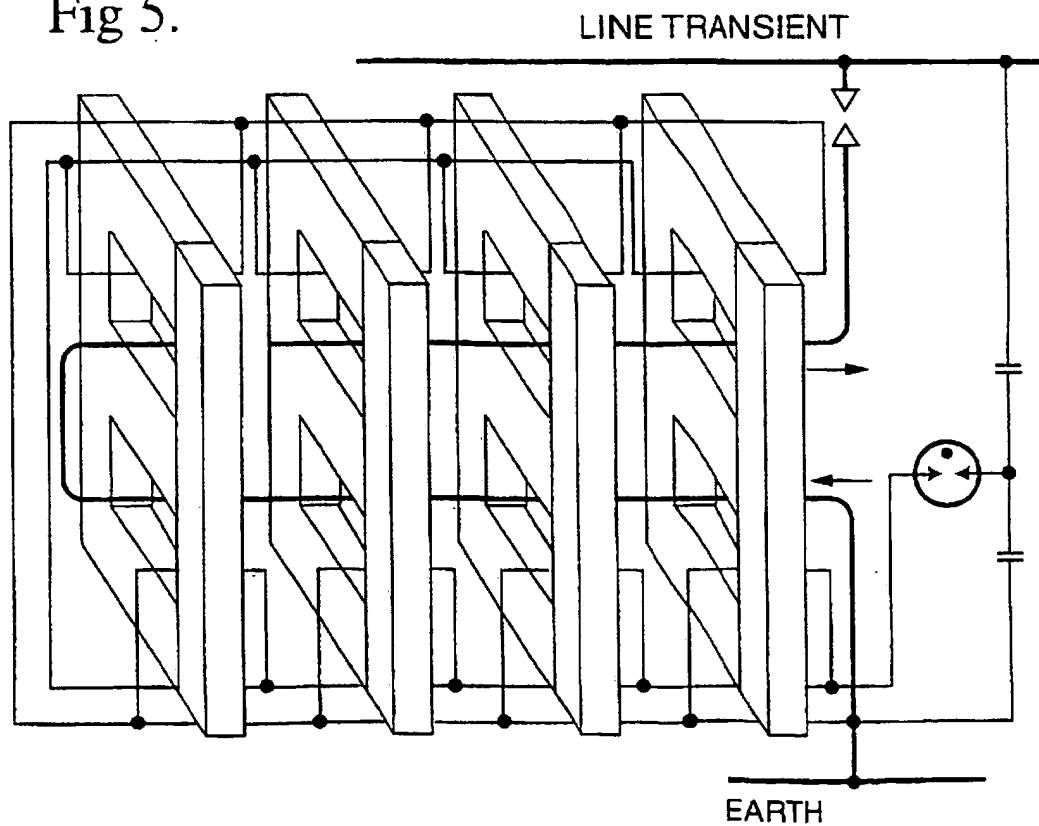


Fig 5.



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Fig 6.

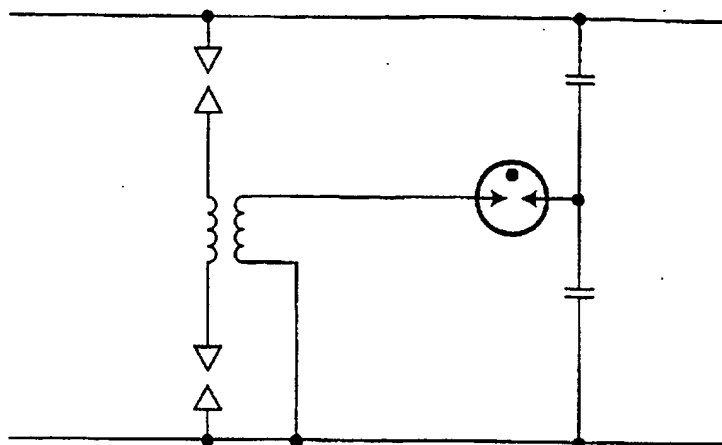


Fig 7.

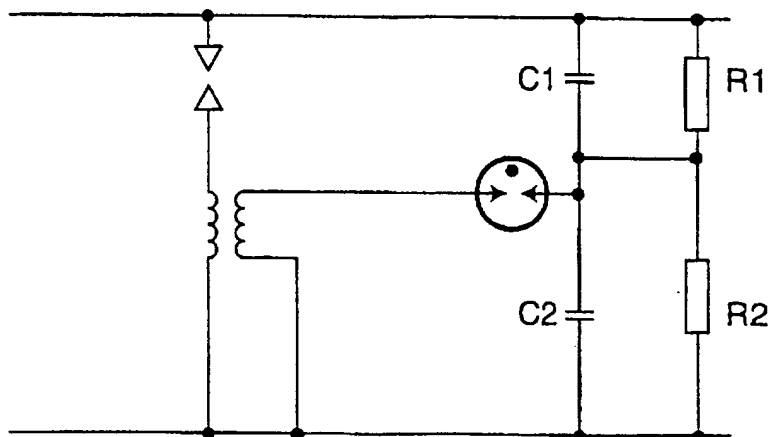
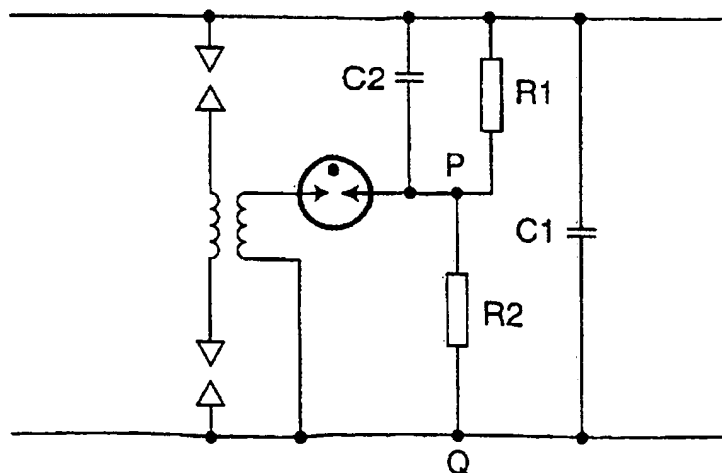


Fig 8.



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Fig 9.

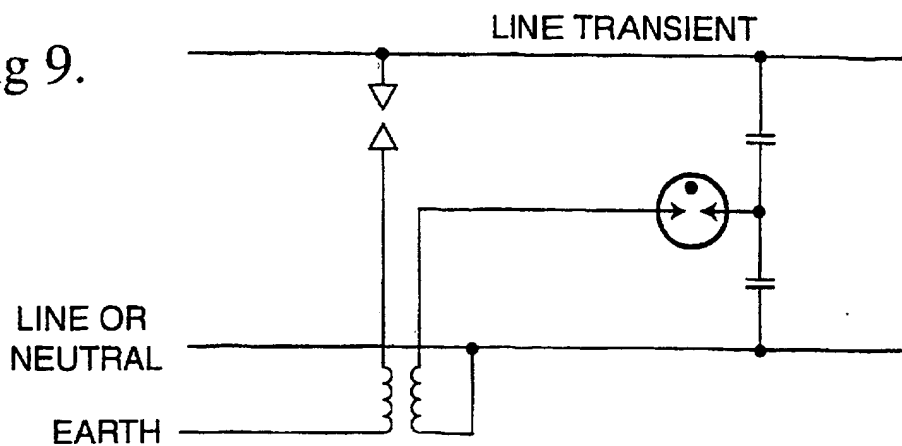
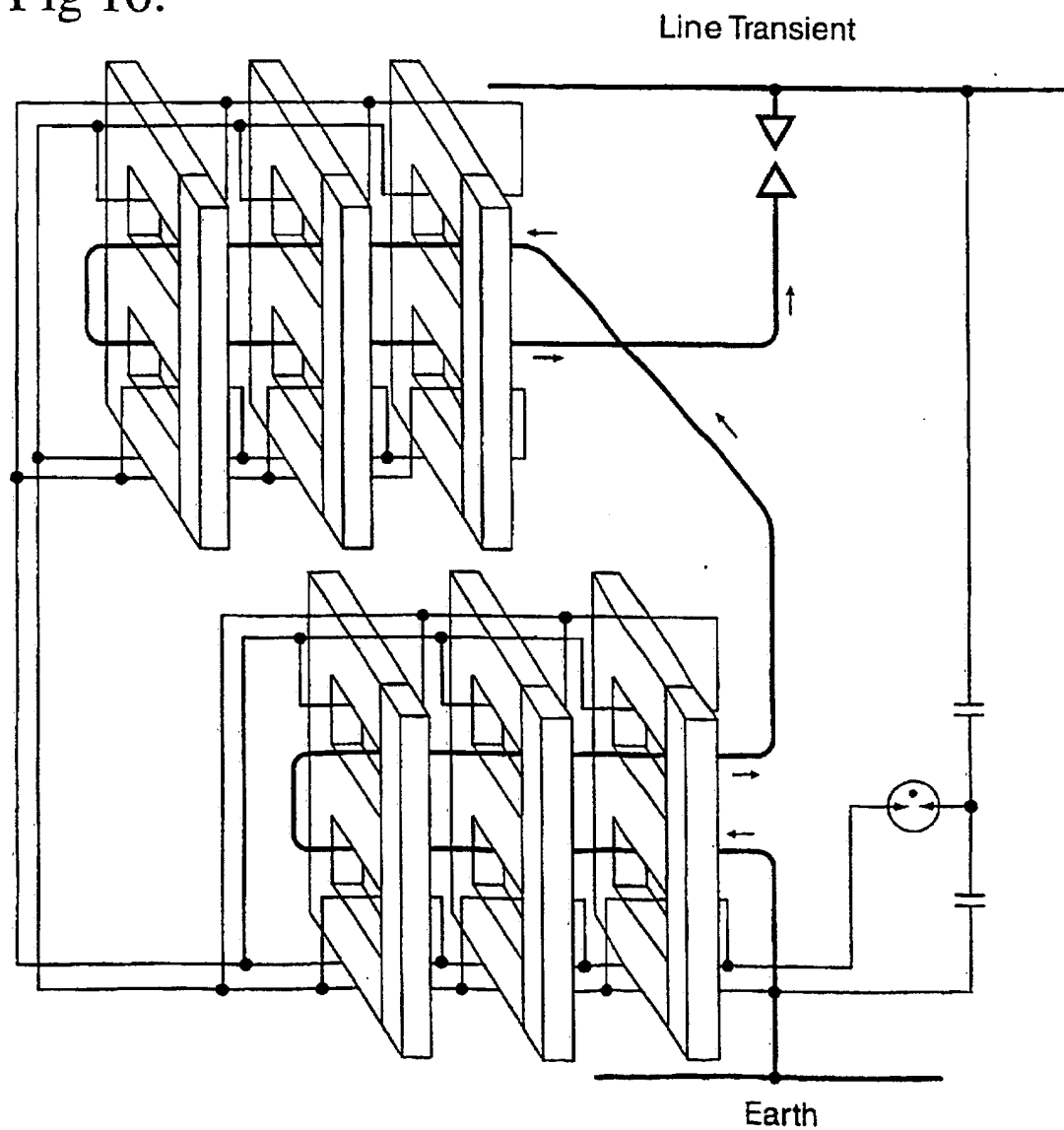


Fig 10.





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Fig 11.

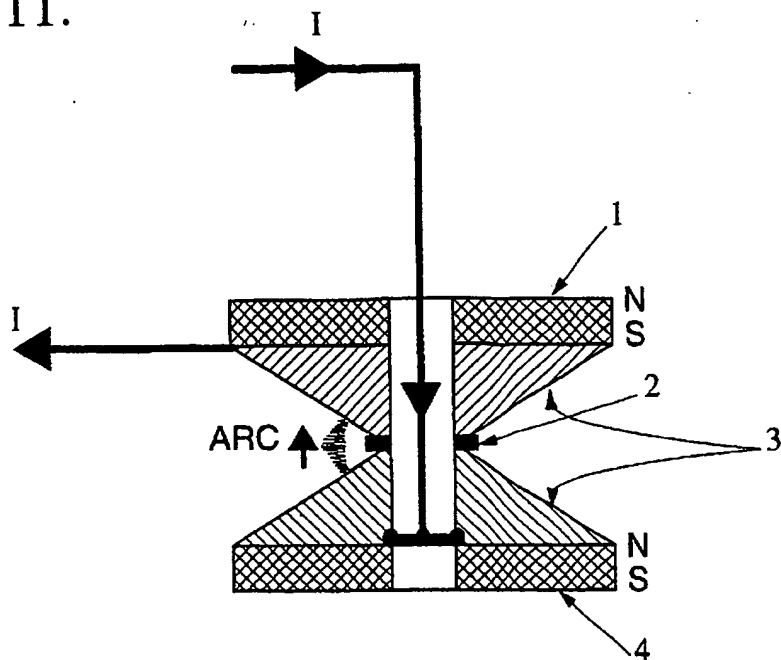


Fig 12c.

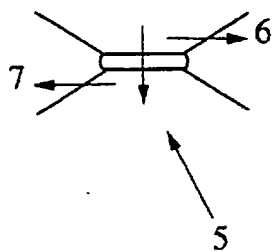


Fig 12a.

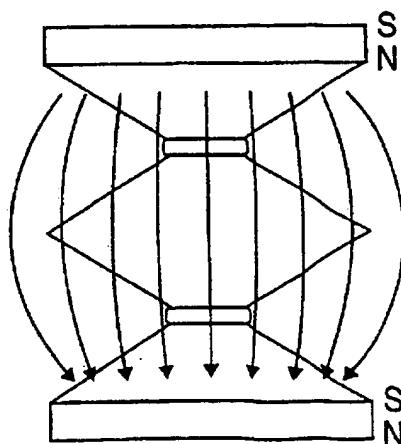
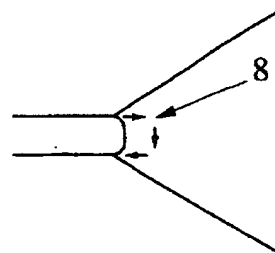


Fig 12b.



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Fig 13a.

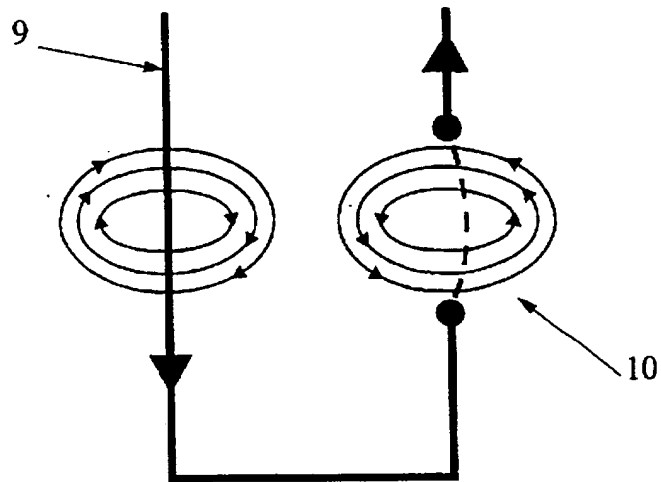
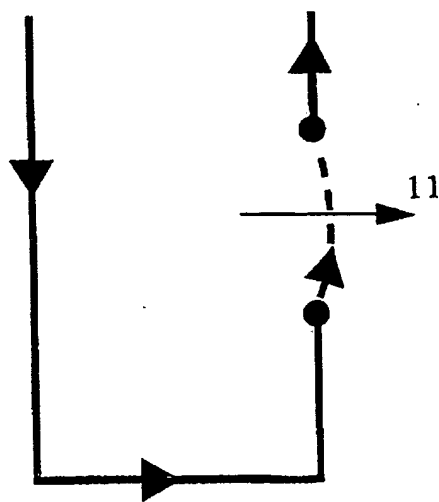


Fig 13b.



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Fig 14a.

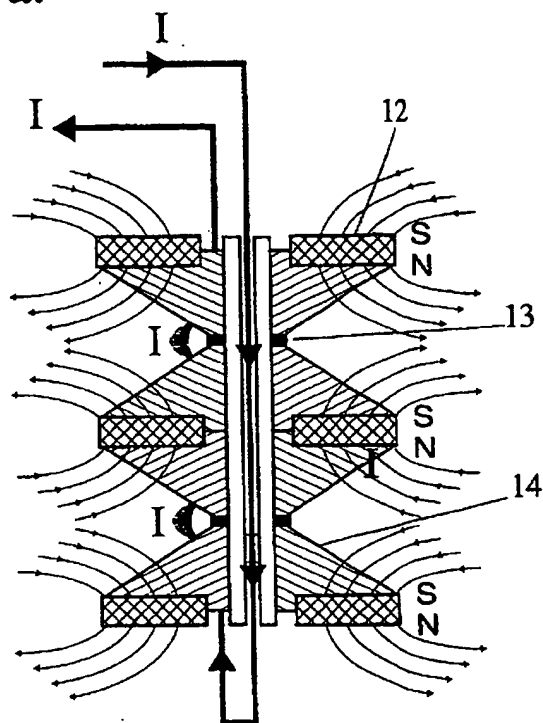
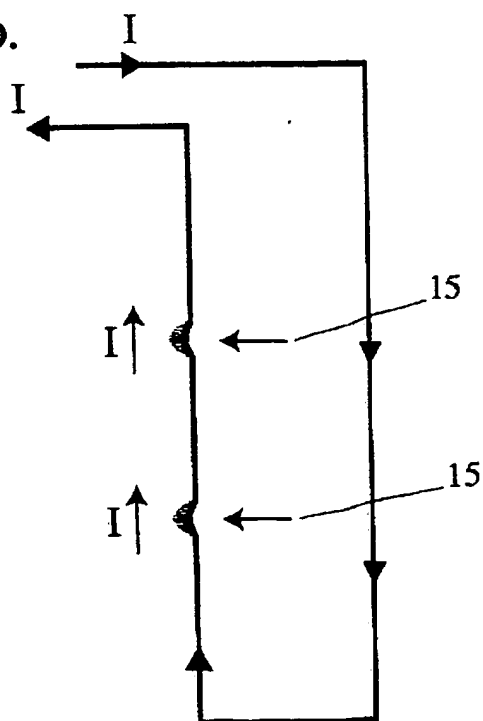
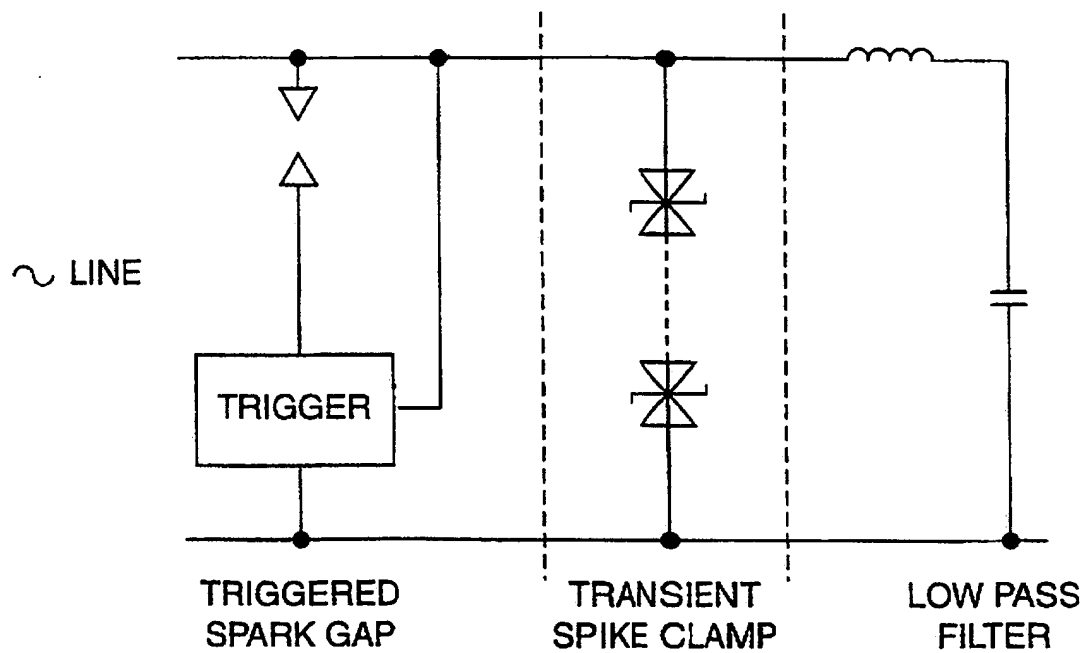


Fig 14b.



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Fig 15.



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